Amendments to the Specification

Please replace the paragraph on page 3, line 24, beginning "Reduction in the requirements needed to implement" with the following amended paragraph:

Reduction in the requirements needed to implement the necessary unitary transformations can lead to simpler, *e.g.* less expensive, more robust, more scalable devices for QIP. For example, in some quantum computers, particular single- and two-qubit unitary transformations (one and two-bit gates) are challenging to implement. Further, single-qubit operations often require specialized systems that increase the potential decoherence of the quantum state hence reducing the overall available computational time before errors occur. Examples of such quantum computers having specialized single-qubit operation systems include quantum dots and donor atom nuclear spins in silicon. See Loss and DiVincenzo, 1998, Physical Review A 57, 120; Levy, 2001, Physical Review A 64, 052306; Kane, 1998, Nature 393, 133; and Mozyrsky *et al.*, 2001, Physical Review Letters 86, 5112 each of which is hereby incorporated by reference in its entirety. In these ~~solid state~~ solid-state systems, single-qubit operations require control over a local magnetic field making them significantly slower than two-qubit operations (mediated by an exchange interaction), and require substantially greater material and device complexity. In the quantum dots in cavity quantum computers each dot needs to be illuminated with a separate laser. See Imamoğlu *et al.*, 1999, Physical Review Letters 83, 4204. Reduction in the number of lasers by elimination of single-qubit operations is a potentially significant technical simplification.

Please replace the paragraph on page 4, line 32, beginning "The single-qubit Pauli Z gate" with the following amended paragraph:

The single-qubit Pauli Z gate (also referred to as a phase flip or 2_{T2}) comprises the σ^Z Pauli matrix, where

$$\sigma^Z = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

In a quantum computer, the single-qubit Pauli Z gate ~~affects~~ effects a phase flip operation on the state of the respective qubit. Here, the single-qubit Pauli Z gate is

applied to the state of qubit Q_1-Q_1 for a period T_2. The periods T_1 and T_3 represent no evolution of the state of qubit Q_1-Q_1.

Please replace the paragraph on page 7, line 3, beginning "The teleportation of quantum" with the following amended paragraph:

The teleportation of quantum ~~state~~ states (quantum state teleportation) holds promise for making fault-tolerant quantum computers more straightforward and methodical. See, Gottesman and Chuang, 1999, Nature 402, 390. Quantum state teleportation is a method for transmitting an unknown quantum state $|\psi\rangle$ from a sender (Alice) to a receiver (Bob) using only classical information. To illustrate this concept, consider quantum circuit 300 (Fig. 3A). There are three qubits in this exchange. The three qubits are denoted by lines 311, 312, and 313 in Fig. 3A. Time proceeds from left to right.

Please replace the paragraph on page 13, line 25, beginning "The superconducting qubit class also includes" with the following amended paragraph:

The superconducting qubit class also includes superconducting charge qubits. See, *e.g.*, Shnirman and Schön, 1998, "Quantum measurements performed with a single-electron transistor," Physical Review B, 57:24, 15400-15407, which is hereby incorporated by reference in its entirety. Another superconducting qubit is the quasicharge ~~qubits~~ qubit described in Cottet *et al.*, 2002, "Implementation of a combined charge-phase quantum bit in a superconducting circuit," Physica C 367, 197, Proceedings of The International Symposium in Superconducting Device Physics (SDP 2001) June 25-27, 2002, which is hereby incorporated by reference in its entirety. A review of superconducting qubits can be found in Makhlin *et al.*, 2001, "Quantum-State Engineering with Josephson-Junction Devices," Reviews of Modern Physics Vol. 73, p. 357, which is hereby incorporated by reference in its entirety.

Please replace the paragraph on page 19, line 23, beginning "At time T1, qubit Q_1 and qubit Q_2 are" with the following amended paragraph:

At time T1, qubit Q_1 and qubit Q_2 are coupled using Josephson gate 210. In embodiments where Q_1 and qubit Q_2 are coupled by a SSET, the Josephson gate 210 is applied by setting the gate voltage of the SSET to a coupling voltage (~~operation~~ <u>operational</u> voltage) for a period of time. In some embodiments of the present invention, Josephson gate 210 includes controlling the coupling term H_{ZZ} of the system Hamiltonian H_S described above. Application of Josephson gate 210 has the effect of applying a Z gate or an R_{IZ} operation on qubit Q_1. At time T2, qubit Q_2 is measured (Fig. 2B, step 220). Measurement 220 has two possible outcomes, 221 and 222. Outcomes 221 and 222 respectively reflect successful and unsuccessful application of the Z gate on the state of qubit Q_1. In other words, outcome 221 means that Josephson gate 210 applied a Z gate to qubit Q_1 and outcome 222 means that Josephson gate 210 did not apply a Z gate to qubit Q_1.

Please replace the paragraph on page 20, line 29, beginning "In Fig. 2B, ancilla Q_2 and a data qubit" with the following amended paragraph:

In Fig. 2B, ancilla Q_2 and a data qubit Q_1 are nearest neighbors. However, the methods of the present invention are not limited to instances where the ancilla qubit and the data qubit are nearest neighbors. In fact, the technique of swapping can be used to move an ancilla qubit to a data qubits or vice versa. See, for example, United States Application Number 09/782,886 entitled, "Optimization Method ~~For~~ **<u>for</u>** Quantum Computing Process," filed February 13, 2001, which is hereby incorporated by reference in its entirety. Some embodiments of the present invention include the use **<u>of</u>** swapping to reduce the number of ancilla qubits that are initialized such that they have an equal superposition of states.

Please replace the paragraph on page 27, line 3, beginning "In an embodiment of the present invention, an instance" with the following amended paragraph:

In an embodiment of the present invention, an instance of a two qubit (qubit i and j) measurement S^2_{ij} is made and this measurement has eigenvalues, and therefore observable S(S+1). If a measurement of two qubits is made, there are two possible outcomes, (i) an observable of 1 (*e.g.* S = 0) and, (ii) an observable of 2 (*e.g.* S =1). Herein, the reference to a result from a ~~two qubit~~ two-qubit measurement refers to the eigenvalue being 1 or 2, (S being respectively 0, or 1). Significantly, this measurement distinguishes between a two-qubit singlet state, $(|0\rangle - |1\rangle)/\sqrt{2}$, and a two-qubit triplet state, $(|0\rangle + |1\rangle)/\sqrt{2}$.

Please replace the paragraph on page 28, line 30, beginning "Outcome 436 is manifested as an observation" with the following amended paragraph in which deleted subject matter is enclosed in bold double brackets **[[ ]]**:

Outcome 436 is manifested as an observation of the triplet state for qubits Q_1 and Q_2. Outcome 436 indicates that the correction step 430 (weak measurement 430) was not successful in applying the one-qubit gate to the quantum state that was on qubit Q_1 prior to measurement 420. If outcome 436 is achieved, a second correction step (440) is needed to apply the one-qubit gate to the quantum state that is now on qubit Q_3. Step 440 comprises measuring the state of first ancillary qubit Q_2 and second ancillary qubit Q_3. Step 440 causes the quantum state that is on qubit Q_3 to transfer to qubit Q_1. Step 440 will result in either successful teleportation of the desired single-qubit operation to the quantum state (now on data qubit Q_1) (446) or the Hermitian conjugate of the desired single-qubit operation to data qubit Q_1 (444). Note that the state that was on data qubit Q_1 prior to measurement 420, and was on the second ancillary qubit Q_3 after measurement 420 and measurement 430, is on the data qubit Q_1 after weak measurement 440. The correction of the Hermitian conjugate **[[**444**]]** of the desired single-qubit operation **[[**446**]]** <u>444</u> to the desired single qubit operation **[[**(446)**]]** <u>446</u> can be achieved without directly applying a one-qubit gate to the quantum state that is now on qubit Q_1. In some embodiments of the present invention, the correction to the Hermitian conjugate of the desired single-qubit operation 444 is made by iterating process 401 and reversing the decision rule. In other words, reversing the action taken after correction steps 430 and 440 such that correction step 430 is only applied when state 424 is observed, correction

step 440 is only applied when state 434 is observed, and Hermitian conjugates are reversed only when states 436 and 446 are observed .

Please replace the paragraph on page 29, line 18, beginning "An embodiment of the present invention includes" with the following amended paragraph:

An embodiment of the present invention includes the use of a correction pulse to implement a correction step. Embodiments of the invention can apply a coupling of qubits Q_j, where j = 1,3 and Q_2 ~~avoiding~~ so as to avoid the repeating of measurements. Embodiments of the present invention can apply,

$$U^{EX}{}_{j2}(\pi/2,0)$$

where,

$U^{EX}{}_{j2}$ is the exchange two-qubit unitary operator.

The coupling takes the Hermitian conjugate of the desired operation $R^{\dagger}{}_{j\beta}$ to the desired single-qubit operation $R_{j\beta}$. Embodiments of the present invention include a correction pulse of the Hamiltonian XY type, where $J^Z = 0$. Embodiments of the present invention include a correction pulse of the XXZ Hamiltonian type, where J^Z is tunable. These Hamiltonians can generate the coupling $U^{EX}{}_{j2}(\pi/2,0)$ and take $R^{\dagger}{}_{j\beta}$ to $R_{j\beta}$. This is the desired operation performed on the qubit indexed as j. In embodiments of the present invention, this correction pulse can be used instead of corrective measurements 430 and 440. In embodiments of the present invention, this correction pulse can be used instead of repeating circuit 401 and reversing the decision rules. The expectation value for the number of steps a correction pulse comprised of the exchange two-qubit unitary operator is 1.

Please replace the paragraph on page 30, line 17, beginning "An embodiment of the present invention includes" with the following amended paragraph:

An embodiment of the present invention includes the use of a correction pulse to implement a correction step. Embodiments of the invention can apply a coupling of qubits Q_1, and Q_2 after two measurements thereby avoiding a third measurement. Embodiments of the present invention can apply,

$$U_{1,2}^{EX}(\pi/2,0)=\begin{bmatrix}1&&&\\&-1&&\\&&-1&\\&&&1\end{bmatrix}$$

where, $U^{EX}{}_{1,2}$ is the exchange two-qubit unitary operator. The coupling takes the Hermitian conjugate of the desired operation to the desired single-qubit operation on the data qubit Q_1. For example, consider an exchange Hamiltonian of the XXZ type with $J^{\perp}(t)$ and $J^Z(t)$ both ~~begin~~ being tunable quantities. Therefore, J^Z is tuned to about zero such that φ^Z is about zero.

Please replace the paragraph on page 31, line 12, beginning "Fig. 5 illustrates a generic embodiment" with the following amended paragraph:

Fig. 5 illustrates a generic embodiment of the process of selective recoupling and rotation. Selective recoupling and rotation are well known from the field of Nuclear Magnetic Resonance (NMR). Starting with step 501, the Hamiltonian of the system is divided into the desired and undesired components, H and B, respectively. The B term is an error term, corresponding to the physical interaction of the register with its environment or with itself. In some embodiments of the present invention, B is a term that is to be altered. In accordance with the given embodiments of the present invention, H and B are expressed as a weighted sum of one and two qubit operators. Next, in step 502, B is determined and for the moment H is disregarded. The recoupling pulse for B, here labeled A, is based on the available controllable interaction in the given quantum register and is determined in step 503. The terms of A should commute with the terms of H. In the examples described in detail above, A is the Josephson coupling proportional to $\sigma^Z{}_i \otimes \sigma^Z{}_j$, a tunneling term proportional to σ^X, a phase flip term proportional σ^Z, or an exchange term such as $H^{ex}{}_{ij}$. The term B is "conjugated by A" in step 504 as detailed below. Step 504 involves a suitably chosen angular parameter φ, whose function is also explained below. The act of conjugation by A physically corresponds to letting the interaction represented by the operator A act on the system for a specific amount of time t. The amount of time t depends on the embodiment of the invention. The result of the process is seen in step 505 whereby the system had its error term conjugated by A. This method can be used with teleported single and two qubit quantum gates.

Please replace the paragraph on page 32, line 24, beginning "Fig. 6A illustrates a quantum circuit 600" with the following amended paragraph:

Fig. 6A illustrates a quantum circuit 600 that implements a composite unitary gate. Unitary gates, including all single qubit unitary gates, can be generated from $R_{j\beta} \equiv \exp(i\frac{\pi}{4}\sigma_j^\beta)$ and the use of selective recoupling and rotations. An example of a composite gate 600 is an X_iX_j gate, expressed as:

$$e^{-i\varphi X_i X_j} = U_{12}(\varphi/2, \varphi^z)\, C_{Xi}^{\pi/2} \circ U_{12}(\varphi/2, \varphi^z).$$

Quantum circuit 600 is comprised of a $-\pi/2$ rotation with R_{iX} operations, an exchange coupling $U_{ij}(\varphi/2,\varphi^z)$ shown as 602, a $\pi/2$ rotation with R_{iX} operations and another exchange coupling $U_{ij}(\varphi/2,\varphi^z)$ shown as 604. The $\pm\pi/2$ rotations can be implemented using two $\pm\pi/4$ rotations shown as 603-1 and 603-2. Next follows an exchange Hamiltonian coupling $U_{ij}(\varphi/2,\varphi^z)$. The $-\pi/2$ rotation on the ith qubit is comprised of two $R^\dagger_{iX}$ operations ~~on~~ shown as 601-1 and 601-2.